# Parametric optimization and Investigation of Mechanical property on 'Keyhole TIG (K-TIG)' weldment of SS-316L

[1]Vinod.D.Golakiya, [2]Nathani Ketankumar V.
[1]Assistant Professor, [2]Post Graduate Student
[1]Department of mechanical engineering
[2]Department of computer aided design and manufacturing
[1,2]Government Engineering College Dahod, India.

***Abstract:*** Keyhole gas tungsten arc welding is recently developed welding process which enables single pass welding without filler metal addition or joint preparation. Keyhole Tungsten inert gas (K- TIG) process with its high productivity and low investment can be successfully used for welding relatively heavy plates. SS316L plates of 8 mm thickness were joined in single pass without filler metal and without joint preparation by keyhole TIG welding. The effect of welding parameters on the fusion zone were investigated. The mechanical properties and material properties of the weld were analyzed. The tensile strength was almost same as the base metal. Hardness is reduced as compared to base metal. Also good penetration ratio was obtained. Numerical optimization was developed for welding process parameter by using response surface method (RSM). Central composite design (CCD) model developed using RSM was reasonably perfect. An attempt has been made to estimate the optimum welding conditions to produce the best possible output within the experimental constraints.
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***Index Terms***: **Keyhole gas tungsten arc welding, SS316L, Mechanical properties, Response surface method, Central composite design.**

## I. INTRODUCTION

TIG welding is an arc welding process that uses non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapor[1].The tungsten electrode and the welding zone are protected from the surrounding air by inert gases. The electric arc can produce temperatures of up to 20000 ℃ and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler metal. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig. 1 & fig. 2 respectively.[2]

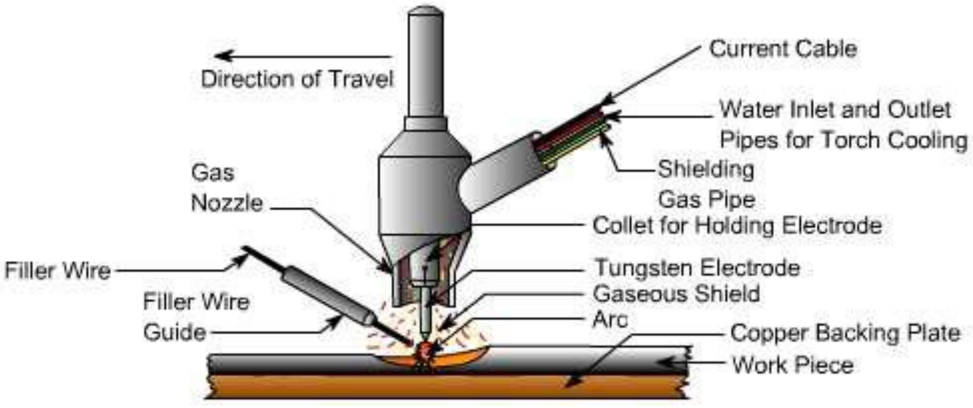

Figure 1 principle of tig welding. [1]

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of electrode depends on whether it is connected to negative or positive terminal of DC power source.

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimetres. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow and it damaging the electrode. Open circuit voltage of power source ranges from 60-80 V[3].

A high-quality weld can be achieved by employing TIG welding. However, the melting depth of a single-pass TIG process is no larger than 3 mm because of the limited penetration ability. A thick work piece requires suitable joint preparation and multi-pass welding is required to deposit additional filling metal into the seam groove. The welding efficiency is thus low and the processing cost is high. Laser beam welding (LBW), electron beam welding (EBW), and plasma arc welding (PAW) are effective methods of joining mid thickness (6–13 mm) work pieces [4]. However, the capital equipment costs of LBW and EBW are high, while the keyholling process in PAW is not that stable. Submerged arc welding is another welding process widely used to join mid-thickness work pieces. The welding efficiency is relatively high compared with that of multipass welding using TIG; however, suitable joint preparation, additional filling metal and additional flux are needed in this process.[5]

Keyhole gas tungsten arc welding (K-TIG) was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) to address these problems with traditional keyhole welding methods. K-TIG was developed based on conventional GTAW. Cooling water circulation was introduced in the constricting nozzle of the welding torch, and a higher welding current was adopted to increase the current density.[6] The electromagnetically induced arc force is much higher in KTIG than in GTAW. This force pushes the liquid metal in the molten pool outward, forming a keyhole. The molten pool anchors itself to the root face of the weldment. The arc force, liquid metal density, and surface tension reach equilibrium, and this keeps the keyhole stable. K-TIG is capable of single-pass, full-penetration welding of thick plates. The equipment and production costs are low and the welding efficiency is very high. Additionally, K-TIG welding is suitable for on-site production.[7]

## II. EXPERIMENTAL PROCEDURE

### a) Experimental Setup:

Keyhole tungsten inert gas welding was performed on base metal specimen of SS316L of dimension 150 X 75 X 8 mm. The base metal is SS316L. Various different direct welding currents were used with electrode negative polarity. Electrode (dia 3.2 mm with tip angle $33^0$) was used with arc length equal to the diameter of electrode. Argon was used as per requirements. No filler material was used in this experiment. Plain butt welds were made. Copper plate was used as backing plate to support the Keyhole Stability. Figure 2 shows a schematic diagram of the experimental setup used.

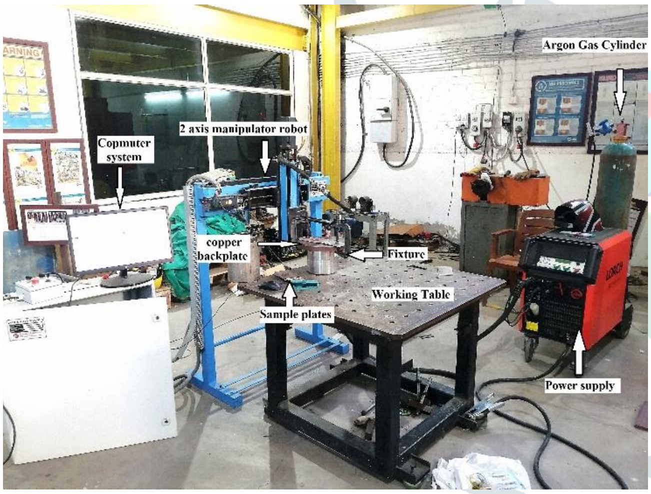

**Figure 2 schematic diagram of the experimental setup**

**Table 1 Chemical composition of SS316L**

| | (%) | Std. Value |
|---|---|---|
| C | 0.019 | 0.03 Max |
| Si | 0.325 | 1.00 Max |
| Mn | 1.4 | 2.00 Max |
| P | 0.029 | 0.045 Max |
| S | 0.020 | 0.030 Max |
| Cr | 16.4 | 16 – 18 |
| Ni | 10.15 | 10 – 14 |
| Mo | 2.24 | 2 – 3 |

To carry out mechanized welding tests using Keyhole TIG welding, a workstation was assembled. This comprised the 2 axis manipulator robot with computer setup. The control over the rate of welding was practiced. The workstation was provided with a clamping system. It was included in workstation which made it possible to clamp the test piece and weld them on copper backing plate.

### b) Material:

Grade 316 is the standard molybdenum-bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments.

**Table 2 Mechanical properties**

| Mechanical Property | Value |
|---|---|
| UTS | 595.36 MPa |
| Micro Hardness | 155.79 |

Base metal's Spectroscopy Test According to ASTM, A 240 was done to know the original chemical composition of the material. It is mentioned in table 1. Mechanical testing of base metal was carried out. Below details had been found out as shown in table 2

### c) Welding Procedure:

To test the effects of welding parameters on the profile of the fusion zone, butt-up welding experiments were conducted in Tests 1–12, as listed in Table 3. Various parameters taken for the experiment is shown in the below table 2.

Response surface methodology (RSM) is a statistical technique to analyze the model and optimize the operation. It is useful for any field of engineering to determine the relationship between the independent process parameters (input factors) with the desired response. In present study, RSM explores the effect of input parameters on response values. From the many classes of RSM, Central Composite Design (CCD) has been selected for the present investigation. CCD is very popular amongst the other RSM methods. CCDs are very efficient, providing much information on experiment variable effects and overall experimental error in a minimum number of required runs. CCDs are very flexible. The availability of several varieties of CCDs enables their use under different experimental regions of interest and operability. Following parameter is consider for design of experiment based on pilot run as shown in Table 2 and Table 3.

**Table 2 various parameters for the experiments**

| Fix Parameters | |
|---|---|
| 1. Workpiece material (SS 316L) | 6. Voltage (13-16 V) |
| 2. Workpiece dimension (150*75*8 mm$^3$) | 7. Arc length (1 to 1.5 times of electrode diameter) |
| 3. Weld type (Plain Butt weld) | 8. Electrode material (tungsten electrode) |
| 4. Edge preparation (No) | 09. Electrode shape (Dia 3.2 mm) Conical tip with $\Theta$=33˚) |
| 5. Preheating (No) | 10. Shielding gas (Ar) |
| **Variable Parameters** | |
| 1. Welding current A (310,325,340) | |
| 2. Welding speed mm/min (75,85,95) | |
| 3. Gas Flow rate L/min (12,14,16) | |

**Table 3 Experimental run based on CCD**

| Run | Current | Welding speed | Gas flow rate |
|---|---|---|---|
| 1 | 325 | 85 | 16 |
| 2 | 325 | 75 | 14 |
| 3 | 310 | 95 | 16 |
| 4 | 310 | 85 | 14 |
| 5 | 340 | 75 | 16 |
| 6 | 325 | 85 | 12 |
| 7 | 325 | 85 | 14 |
| 8 | 325 | 85 | 14 |
| 9 | 340 | 95 | 12 |
| 10 | 310 | 75 | 12 |
| 11 | 340 | 85 | 14 |
| 12 | 325 | 95 | 14 |

### d) Measurement of Experimental Responses:

After welding experiments, required outputs were Tensile strength, penetration ratio and hardness.

#### i. Penetration ratio:

Here in our experiment we get the full penetration in all samples so we used the ratio of Wb/Wf. Weld profile is required to measure the upper and lower width of the weld

#### ii. Hardness:

To measure the Vickers micro hardness, test surface usually must be highly polished because for smaller force higher the metallographic finish required. Fig, 4.4 shows the machine for micro Hardness.

#### iii. Tensile Strength:

Tension test specimen confirms the ASME SEC IX @2013. According to the standard the full thickness specimen was used for thickness less than 25mm. Geometrical dimensions of the test samples are shown in figure 4.5

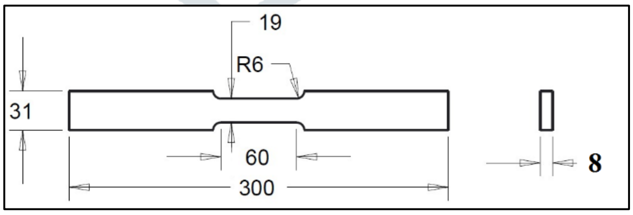

**Figure 3 Dimensions of Tensile Test Specimen**

## III.RESULT AND DISCUSSION

### A. Effects of welding parameters on the UTS:

Here the graph for UTS as shown in figure. From the graph we can say that at minimum welding speed as we increase the current the UTS value slightly decrease. Same way with maximum speed as we increase the current the UTS value decreases. Also at any current value as we increase welding speed, UTS is decreasing. Effect of gas flow rate on hardness is very little.

Main reason behind this decreasing of UTS with respect to increase in current is that at higher current undercut is formed, which can be seen visually. Also increasing welding speed at any current value, decreasing the Heat input which decrease the UTS. Max UTS we get is 579.06 which is 97.26 % of the base metal.

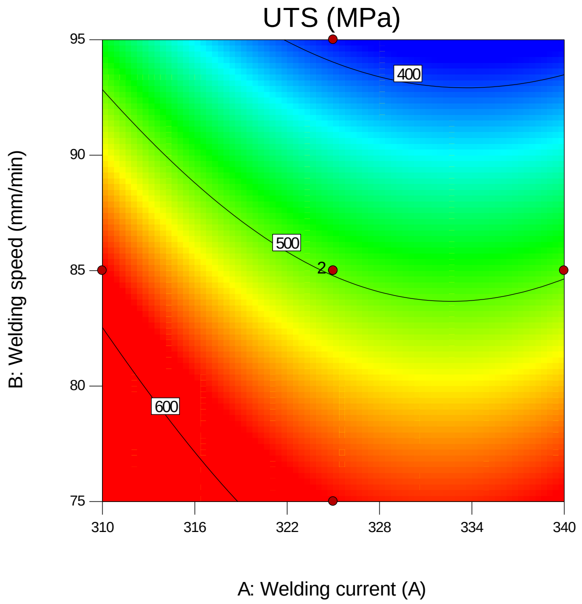

**Figure 4**

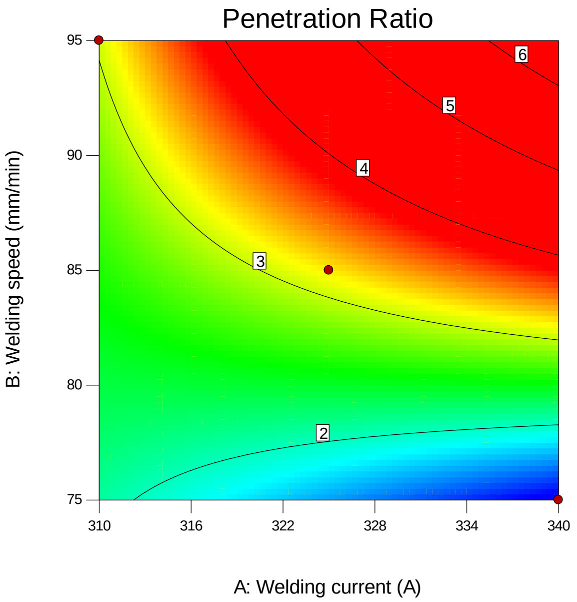

**Figure 5**

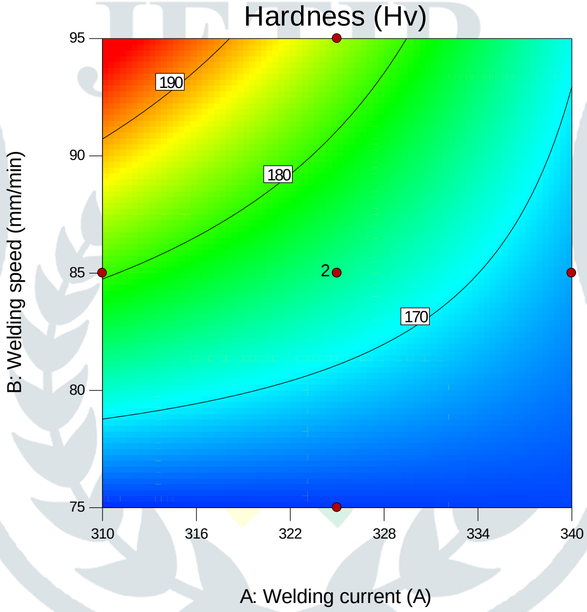

**Figure 4**

## B. Effects of welding parameters on the Penetration Ratio:

From the graphs, we can say that with minimum welding speed as we increase welding current the penetration ratio decrease. At minimum speed enough heat input is applied for enough time so that the back width of the weld is increased which gives the penetration ratio very close to 1.

## C. Effects of welding parameters on the Hardness:

From the graph figure 6 we can say that for all gas flow rate, with minimum welding speed as we increase the welding current, we get the high hardness value. Maximum welding current and minimum welding speed gives us the low hardness, minimum welding current and maximum welding speed gives us the high Hardness.

Typically, the hardness of the material is affected by the microstructure, phase, and grain size. The hardness of the finer dendritic structure in the weld is also higher than that of the coarser equiaxed grains in the base metal. Therefore, the weld is harder than the base metal. Effect of gas flow rate on hardness is very little.

## IV. CONCLUSION

The present study develops a procedure for the Keyhole TIG welding of SS316L by taking various input parameters and then the results are verified. In this procedure edge preparation and joint preparation are not done and get the required result in a single pass. The present study also develops optimization for Keyhole TIG welding process of SS316L material using response surface method. It is found that three parameters and some of their interactions have a significant effect on responses considered in the present study. Finally, an attempt has been made to estimate the optimum welding conditions to produce the best possible output within the experimental constraints.

1. Single-pass K-TIG welding can be applied to 8-mm-thick SS316L without filler wire addition or edge preparation.
2. The strength of the weld is almost the same as that of the base metal. Undercut is observed at high Current and thus did not give the higher strength at high current.
3. The Central Composite Design (CCD) model developed using RSM were reasonably perfect and can be used for prediction within the limit of factors investigated.
4. The optimal condition of input variables is at 310 A of welding current, 75 mm/min of welding speed and 12.751 L /min of gas flow rate to get the required value of each response.

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